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LIFTIX: Software for Evaluation of Lifting Posture Integrating Ergonomics and Machine Learning

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ABSTRACT

Lumbar load in the lifting posture has been evaluated and improved to prevent lower back pain in various occupational fields, as awkward postures lead to lower back pain during manual lifting. Generally, lifting posture and lumbar load are evaluated through human observation or technical musculoskeletal simulation. Human observation has limitations in terms of repeatability and accuracy. Musculoskeletal simulators require professional skills and operational time for accurate analyses. Therefore, an easy and accurate system for evaluating lifting postures is required. Thus, the objective of this study was to develop and verify easy and accurate evaluation software for lifting postures that can be used by beginners for ergonomic posture assessment. The developed LIFTIX system calculates the compression force of L5-S1 using a combination of the Hand-Calculation Back Compressive Force Estimation Model (HCBCF) and machine learning-based pose estimation using the MediaPipe model. In addition, LIFTIX has functions for computational simulation between parameters of the biomechanical model, such as the joint angle and compression force of the L5-S1. Furthermore, these calculations and functions can be performed using a graphical user interface (GUI). In the experiment, the accuracy of the developed system, LIFTIX, was verified by comparing it with an existing ergonomic musculoskeletal simulator (3DSSPP) for 10 lifting postures. The results showed that LIFTIX could automatically evaluate the compression force of L5-S1 with a significantly high correlation ($r=0.794$, $p<0.05$) with the existing musculoskeletal simulator. These results indicate that the developed LIFTIX system can be used to evaluate lifting postures in workplaces.

General Terms

Software, Graphical User Interface (GUI), Computer Application, Computer Vision, Computational Simulation, Machine Learning, Pose Detection, Biomechanics, Biomedical Engineering, Ergonomics, Posture Assessment, Lower Back Pain, Lumbar Loads, Manual Lifting, Occupational Health.

Keywords

LIFTIX, Python, PyQt6, MediaPipe, Compression Force of L5-S1, Hand-Calculation Back Compressive Force Estimation Model (HCBCF).

1. INTRODUCTION

Occupational lifting is one of the causes of lower back pain among workers [1], [2], [3]. In particular, awkward lifting postures, such as trunk bending, should be avoided to prevent lower back pain [4], [5], [6]. Thus, lifting postures are observed and improved by experts in occupational ergonomics [7], [8]. Human observation has limitations in terms of accuracy and repeatability [9]. Automatic posture evaluation systems using image processing for manual lifting have been developed [10], [11]. These systems can recognize several lifting postures with different lumbar loads; however, they cannot predict the quantitative lumbar loads, such as the compression force of the vertebrae. The compression force of L5-S1, as a quantitative lumbar load, is useful for evaluating lifting postures because there is an injury threshold of 3400 N in the compression force of L5-S1 [12]. Musculoskeletal simulators, such as 3DSSPP, can evaluate quantitative lumbar loads, including the compression force of L5-S1 [13], [14]; however, these simulators require professional skills and operation time for an accurate analysis. Therefore, an easy and accurate system for evaluating lifting postures is required.

The objective of this study was to develop and verify easy and accurate evaluation software for lifting postures that can be used by beginners for ergonomic posture assessment.

2. DEVELOPED SYSTEM "LIFTIX"

2.1 Overview

The developed system LIFTIX calculates the compression force of L5-S1 from a photo of the lifting posture using a combination of an ergonomic biomechanical model and a machine learning-based pose estimation model. LIFTIX is executable as an EXE file in the Windows 11 operating system. LIFTIX was developed and implemented in Python. The LIFTIX icon is shown in Fig 1. The system requirements for LIFTIX are presented in Table 1.

The graphical user interface (GUI) of LIFTIX is shown in Fig 2. The GUI of LIFTIX was implemented using the Python library, PyQt6 [15]. The GUI provides an input photo, weight of lifting, and body measurements (body height and body weight) for manual lifting. In addition, the GUI can display the detected landmarks on the body and the calculated joint angles, segment lengths, and lumbar load (compression force of the L5-S1). The features and functions of LIFTIX are described as follows.

Fig 1: Icon of the LIFTIX

Table 1. System requirements for the LIFTIX

Requirements	
Operating System	Windows 11
Disk Space	At least 100 MB
Display Resolution	1280×720 pixels or higher
Internet	Not required

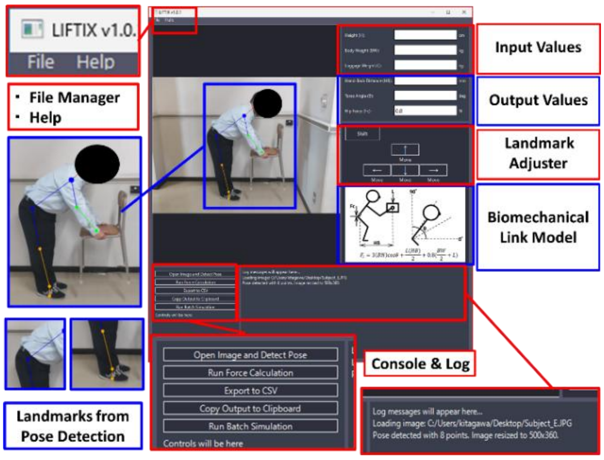

Fig 2: GUI of the LIFTIX

2.2 Calculation of lumbar load

The flow of the lumbar load calculation from the photo is shown in Fig 3. First, the photo, weight of lifting, and body measurements (body height and body weight) of manual lifting were input into LIFTIX. Second, landmarks for calculating the joint angles and segment lengths were automatically detected using MediaPipe [16], which is a machine learning-based pose detection model. Third, the joint angles, segment length, and horizontal distance between the hand and hip were calculated using landmark positions and body height. Finally, the compression force of L5-S1 as the lumbar load was calculated using the Hand-Calculation Back Compressive Force Estimation Model (HCBCF) [17] with body measurements, joint angles, segment lengths, and horizontal distance between the hand and hip. In addition, LIFTIX can simulate the relationship between the compression force of L5-S1 and parameters such as the trunk angle. An example of a computational simulation between the trunk angle and compression force L5-S1 is shown in Fig 4. Users can input multiple continuous parameters using text files. Furthermore, LIFTIX can export calculation results via CSV files or the clipboard.

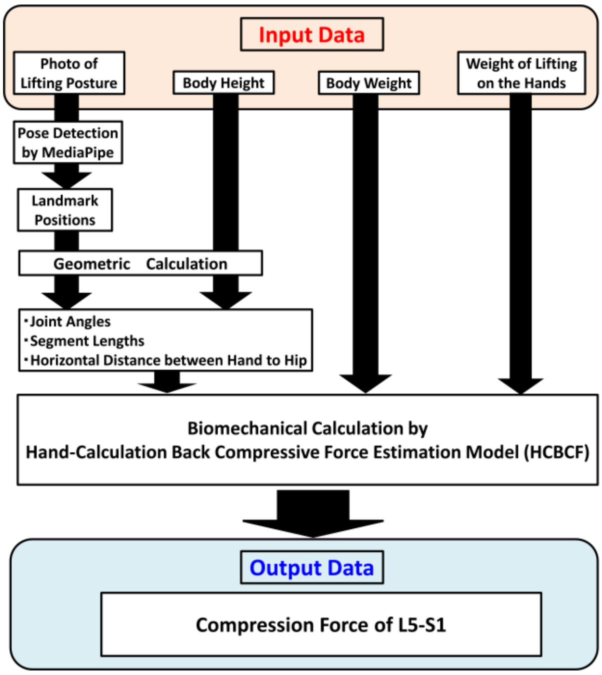

Fig 3: Flow of the Lumbar load Calculation

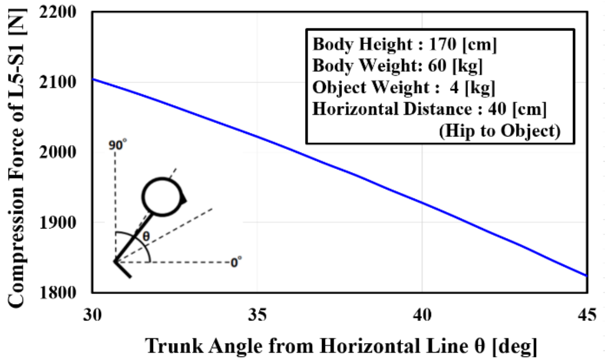

Fig 4: Example of Computational Simulation (Trunk Angle vs. Compression Force of L5-S1)

2.3 Other functions

As mentioned previously, LIFTIX can automatically detect landmark positions using the MediaPipe. However, the detected landmark positions sometimes differ from the actual joint positions. Thus, users can modify landmark positions using keyboard operations with a landmark adjuster. The operation panel of the landmark adjuster of LIFTIX is shown in Fig. 5. Users can move the landmark position using the arrow keys (up, down, left, and right keys). In addition, combinations of arrow keys (up and down) and the Shift key provide saving and resetting functions of the landmark position. Furthermore, users can select a landmark for position adjustment using combinations of the arrow keys (left and right) and the Shift key. The operation panel using the Shift key and arrow keys is shown in Fig. 6. The keyboard operation list for the landmark adjuster is presented in Table 2.

LIFTIX provides help functions (documentation) similar to general computer applications. Fig 7 shows an example of the help window. The help functions provide various explanations in English and Japanese languages. LIFTIX allows both SI and USCS units for the system of units in the data inputs and outputs. Users can switch the units of the system in LIFTIX.

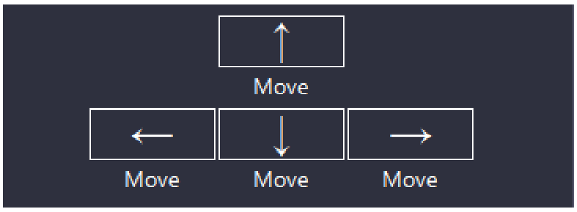

Fig 5: Operation Panel of Landmark Adjuster

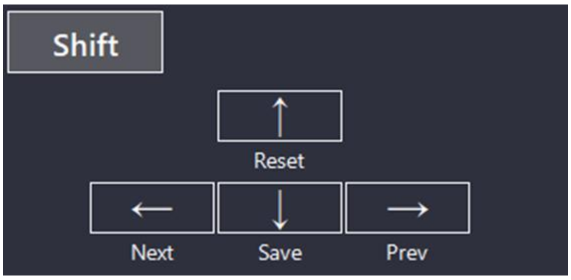

Fig 6: Operation Panel with Shift Key

Table 2. Operation List of Landmark Adjuster

Keyboard Operation	Function
Arrow (↑ ↓ ← →)	Moving landmark position
Shift + Arrow (↑)	Resetting landmark positions
Shift + Arrow (↓)	Saving landmark positions
Shift + Arrow (← →)	Selecting landmark

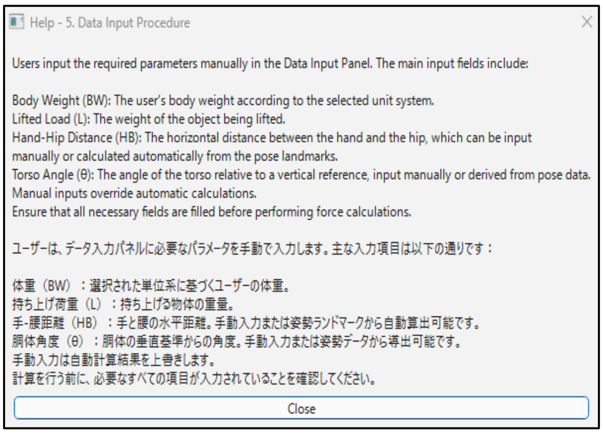

Fig 7: Example of Help Window

3. EXPERIMENTAL EVALUATION

The accuracy of LIFTIX was evaluated by an experimental comparison with 3DSSPP as an existing ergonomic musculoskeletal simulator.

3.1 Participants and ethical approval

The participants were 10 young males. The characteristics of the participants are presented in Table 3. This experiment was conducted in accordance with the Ethics Committee for Human Research of the National Institute of Technology, Hachinohe College (approval number: R7-1).

Table 3. Characteristics of Participants

Characteristics (Mean ± S.D.)	
Gender	Male (all)
Age [years]	19.6 ± 0.5
Body Height [cm]	170 ± 4
Body Weight [kg]	70.8 ± 13.0

3.2 Experimental procedure

The participants performed the lifting posture for evaluation. The weight of the object was 4.85 kg in the lifting posture. Lifting postures in the sagittal plane were captured to calculate the compression force at L5-S1. The body measurements of the participants, weight of the object, and photographs of the lifting posture were used as inputs for both LIFTIX and 3DSSPP. Fig 8 shows an example of a captured lifting posture.

Both LIFTIX and 3DSSPP calculated the compression force of L5-S1 in the lifting postures. The adjustment of the musculoskeletal model in the 3DSSPP was performed by a researcher in the ergonomics field with more than 10 years of experience. In contrast, LIFTIX automatically calculates the compression force at L5-S1 without adjustment. Note that the landmark adjustment function of LIFTIX was not used in this experiment.

Fig 8: Example of Lifting Posture

3.3 Data analysis

The compression forces at L5-S1 were compared between the LIFTIX and 3DSSPP groups. The root mean square error (RMSE) of the compression force of L5-S1 between LIFTIX and 3DSSPP was calculated as the prediction error of LIFTIX. Spearman's rank correlation coefficient for compression force of L5-S1 between LIFTIX and 3DSSPP was calculated as accuracy of LIFTIX. In addition, the difference in the compression force of L5-S1 between LIFTIX and 3DSSPP was tested using Wilcoxon's signed-rank test. The significance level was set at $p<0.05$. Statistical analyses were performed using EZR software [18].

4. RESUTS

The box and scatter plots of the compression force of L5-S1 calculated from LIFTIX and 3DSSPP are shown in Fig 9 and 10, respectively. Spearman's rank correlation coefficient and RMSE of compression force of L5-S1 between LIFTIX and 3DSSPP are shown in Table 4. The results showed that LIFTIX could predict the compression force of L5-S1 with a significant and high correlation ($r=0.79$, $p<0.05$) with 3DSSPP as a conventional musculoskeletal simulation. In addition, there was no significant difference ($p>0.05$) in the compression force of L5-S1 between the LIFTIX and 3DSSPP. Furthermore, the RMSE of the compression force of L5-S1 between LIFTIX and 3DSSPP was less than 500 N.

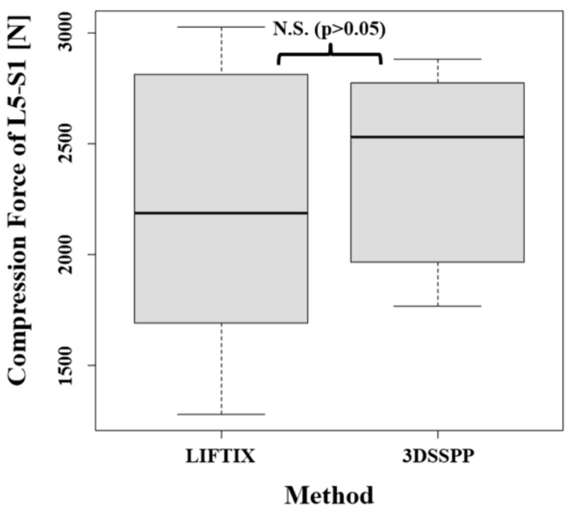

Fig 9: Box Plot of Compression Force of L5-S1

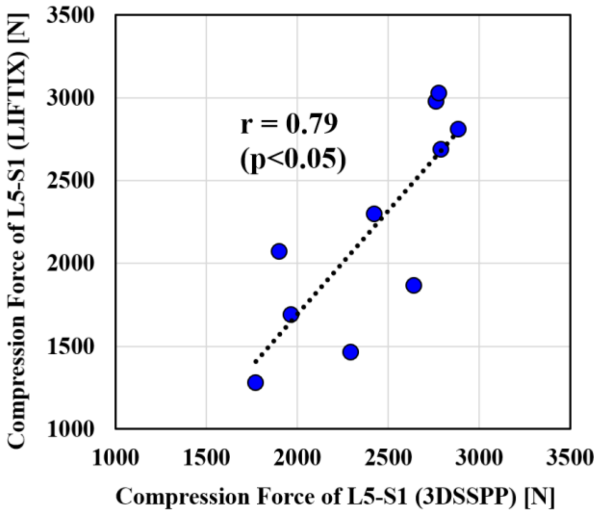

Fig 10: Scatter Plot of Compression Force of L5-S1

Table 4. Correlation and RMSE of LIFTIX and 3DSSPP (Compression Force of L5-S1)

Results of Comparison	
Spearman's rank correlation coefficient	r = 0.79
	p<0.05
RMSE [N]	420

5. DISCUSSION

The experimental results showed a significant correlation in the compression force of L5-S1 between LIFTIX and 3DSSPP. In addition, there was no significant difference in the compression force of L5-S1 between LIFTIX and 3DSSPP. Furthermore, the RMSE of the compression force of L5-S1 between LIFTIX and 3DSSPP was less than 500 N. These results indicate that the developed LIFTIX system can accurately predict the compression force of L5-S1 in the lifting posture. These results suggest that LIFTIX can be used for easy and accurate monitoring of lumbar loads during manual lifting.

As mentioned previously, the landmark adjuster of LIFTIX was not used in this experiment. The accuracy of LIFTIX may be improved by using a landmark adjuster. The effects of landmark adjusters on LIFTIX will be investigated in future studies. In addition, other machine learning models, other than MediaPipe, will be compared to improve the accuracy of LIFTIX. Furthermore, biomechanical models other than the HCBCF will be investigated to improve accuracy.

The limitation of this study is that several parameters of the lifting posture, such as the weight of the object, were fixed in the experiment. In future studies, LIFTIX should be tested and modified via further experiments under various conditions. In addition, LIFTIX requires extensive evaluation considering various datasets or scenarios.

6. CONCLUSION

The objective of this study was to develop and verify easy and accurate evaluation software for lifting postures that can be used by beginners for ergonomic posture assessment. The developed software LIFTIX can easily and automatically predict the compression force of L5-S1 in the manual lifting posture using MediaPipe and HCBCF.

The experimental results showed that LIFTIX could accurately predict the compression forces of L5-S1 in 10 lifting postures. These results suggest that LIFTIX can be used for easy and accurate monitoring of lumbar load during manual lifting.

In future studies, LIFTIX will be tested and modified for various environments. In addition, the pose detection and biomechanical models will be modified to improve the accuracy of LIFTIX.

7. ACKNOWLEDGMENTS

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